RAC 1095
(SRS-QPR-62-330)
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# Quarterly Progress Report No. 3

(1 September 1962 to 30 November 1962)

# MAGNETIC INDUCTION GYROSCOPE RESEARCH AND DEVELOPMENT

Prepared for
Bureau of Naval Weapons
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Contract NOw 62-0660-d



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<u>PROPRIETARY INFORMATION</u>

## ABSTRACT

This report describes the theoretical and experimental research and development work on the magnetic induction gyroscope during the period 1 September 1962 through 30 November 1962, in accordance with Contract NOw 62-0660-d.

Prior research and development on the magnetic induction gyroscope resulted in the establishment of a nuclear resonant signal utilizing simulated rotation, i.e., the generation of a voltage, dependent upon a simulated rotational velocity, in a suitably located coil. The complete verification of gyroscopic behavior as theoretically predicted requires the use of an actual rotating model. This model was designed, its construction completed early in the quarter, and preliminary simulated rotation experiments were initiated. Simultaneously, additional experiments utilizing the simulated rotation model continued.

Activities during the next quarter will be concentrated on the further development of the magnetic induction gyroscope rotating model.

## TABLE OF CONTENTS

# SECTION I - INTRODUCTION

## A. A BRIEF REVIEW OF THE BASIC THEORY

Placement of a single proton in a constant magnetic field will result in the precession of its magnetic moment vector about the direction of the magnetic field. The placement of many protons (as contained in water, for example) into a similar field will result in quite a different situation because of the proton spin interactions with each other and with the "lattice" motions. In such a case, the resultant magnetic moment of the entire assemblage will have its longitudinal (parallel to the field) component approach exponentially a final value and its transverse component disappear exponentially. These ordering processes take place in finite amounts of time defined as the "relaxation times." If the magnetic field has a variable component with a period much less than the relaxation time but the field is still unidirectional, the behavior of the resultant magnetic moment is not essentially changed. The presence of a magnetic field at right angles to the above field, however, produces a resultant magnetic field which is variable in both amplitude and direction. The action of this field produces a highly perturbed precession of the resultant magnetic moment vector, i.e., the precessional axis tries to follow the constantly changing direction of the magnetic field. The finite relaxation time, being greater than the period of the a-c field, prevents the alignment of the precessional axis with the direction of the magnetic field. The presence of this perpendicular or side field can be shown to be equivalent to rotation of the variable amplitude unidirectional field and nuclear sample (as might be caused by the rotation of a vehicle to which the field-producing mechanism is attached). The magnitude of this side field is proportional to the speed of rotation of the vehicle.

The foregoing can be summed up mathematically by the equation:

$$\frac{d\vec{M}}{dt} = \gamma \vec{M} \times \left( \vec{B} + \frac{\vec{\omega}}{\gamma} \right) + \vec{R} \tag{1}$$

where $\vec{M}$ is the resultant magnetic moment of all the protons (as observed in the rotating system),

$t$ is the time,

$\gamma$ is the ratio of the magnetic moment of a single proton (or electron) to its angular momentum,

$\vec{B}$ is the resultant magnetic field,

$\vec{\omega}$ is the angular velocity of the rotating system,

$\vec{R}$ is the rate of change of magnetic moment due to the relaxation effects.

Action as a gyroscope can be explained as follows: Two "pickup" coils can be wound around the nuclear fluid (source of protons) container in two perpendicular planes so that the axes of both coils are perpendicular to the direction of the a-c magnetic field. Since there is no cutting of magnetic flux lines of this a-c field, no voltages are induced in the pickup coils. If, however, the vehicle in which the magnetic induction gyroscope is placed has an angular velocity, the perturbed precessional effects discussed previously will take place. In this case, the resultant magnetic moment vector of the nuclear sample, because of its perturbed motion, causes magnetic lines of flux to link both pickup coils. The resulting induced voltage, although a periodic function, is obviously nonsinusoidal. A complete analysis indicates a large harmonic content, but the second harmonic may be made to predominate. Thus it is the second harmonic component that is measured.

The induced voltages depend on the amplitude and frequency of the magnetic field such that a peak or resonance occurs under certain conditions. The frequency of the a-c field is such as to "prime" the natural precessional frequency, being made the same as, or a subharmonic of, the natural precessional rate. Thus action as a two-axis rate gyroscope takes place. Integration of these signals through suitable feedback circuits will result in a two-axis rate integrating gyroscope. Under certain conditions (dependent upon relaxation times) this integration is inherent in the basic gyroscopic operation.

The preceding is discussed in much greater detail in Quarterly Progress Report No. 1.*

* Quarterly Progress Report No. 1 (1 March 1962 to 31 May 1962), MAGNETIC INDUCTION GYROSCOPE RESEARCH AND DEVELOPMENT - Republic Aviation Report No. RAC 815 (SRS-QPR-62-314).

## B. REVIEW OF PREVIOUS WORK

Previous research and development on the magnetic induction gyroscope resulted in the design of a simulated rotation model, the rotation being simulated by means of a side or perpendicular magnetic field. For simplicity in construction of the experimental apparatus, a single pickup coil was used to indicate this simulated rotation in a single direction only. A Helmholtz pair of coils was used as the polarizing coil, i.e., the coil used to provide the variable magnitude, unidirectional magnetic field. The polarizing coil was energized with suitable a-c and d-c currents to produce the proper field configuration. The rotation-simulation field was produced by another pair of Helmholtz coils positioned with their axes perpendicular to the polarizing coil axis and energized by a d-c current.

With magnetic fields of the mathematically computed proper values, a nuclear resonant second harmonic signal occurred of magnitude very close to the predicted value. Succeeding experiments improved the quality of this signal.

The establishment of nuclear resonance using simulated rotation thus brought the research and development of the magnetic induction gyroscope to its next stage, that of establishing nuclear resonance using actual rotation. A rotating model (combination magnetic induction gyroscope and rotation providing test fixture) was designed and its fabrication initiated prior to the current quarterly period.

## SECTION II - CURRENT ACTIVITY

### A. INTRODUCTION

The fabrication of the magnetic induction gyroscope rotating model was completed early in the current period. Preliminary experimentation commenced, but a successful nuclear resonance using simulated rotation has not been attained due to various mechanical problems.

### B. THEORETICAL CONSIDERATIONS

Previous reports have discussed the relationship between magnetic field homogeneity and resonant signal magnitude. It has been brought out that the presence of large numbers of protons in the sample results in a distortion of the magnetic field at various points throughout the nuclear material. This distortion is caused by the somewhat random local fields created by the protons. The preceding action was seen to be one of the fundamental causes of the relaxation process. Thus it became apparent that any external field inhomogeneity would produce a similar effect, the effective transverse relaxation time becoming a function of the external field inhomogeneity. Mathematically this statement becomes:

$$\frac{1}{T_2^*} = \frac{1}{T_2} + \gamma \Delta B$$

where $T_2^*$ is the effective transverse relaxation time,

$T_2$ is the actual transverse relaxation time,

$\gamma$ is the gyromagnetic ratio,

$\Delta B$ is the rms magnetic field inhomogeneity.

The effective transverse relaxation time can thus be determined only by knowing the magnetic field homogeneity as a function of spatial position within the nuclear sample. It was previously indicated that the mathematical computation of homogeneity was an extremely tedious process. The computations, however, could only predict the homogeneity based upon physical dimensions and spacings of the coils producing the field. The predicted homogeneity would thus become a function of actual measurements, subject to human error. The only accurate determination of homogeneity becomes the actual point-to-point measurement of the magnetic field. This, however, is an impractical approach, since there is no known instrument capable of measurement to the accuracies desired.

With this theoretical background, it is seen that the measurement of magnetic field homogeneity must be made by a more sophisticated means. Since the resonant signal magnitude is a function of magnetic field homogeneity, the magnitude of the signal (and the resonance line width) also becomes a measure of the homogeneity. It is planned to use data obtained from simulated rotation tests of the rotating model (using pure water) to compute the homogeneity of the magnetic field produced by the Braunbek coils. The data sought is the relationship between pickup coil output signal magnitude and both rotation-simulation coil current and polarizing coil d-c current. The computed magnetic field homogeneity figure will then serve as a foundation for the computation of parameters (coil currents) for use in actual rotation experiments utilizing pure water as a nuclear sample. It is to be noted that the copper nitrate doped nuclear sample used in the present simulated rotation experiments has a relatively short actual transverse relaxation time (in the order of 350 microseconds), so that the magnetic field homogeneity factor does not become significantly large in the computation of effective relaxation time. Reference is made to the equation for effective relaxation time stated earlier.

## C. EXPERIMENTAL RESULTS

The previous report* discussed in detail the problem of second harmonic distortion (52 kc current) in the polarizing coil. The current quarterly period

*Quarterly Progress Report No. 2 (1 June 1962 to 31 August 1962), MAGNETIC INDUCTION GYROSCOPE RESEARCH AND DEVELOPMENT - Republic Aviation Report No. RAC 919 (SRS-QPR-62-323)

saw increased effort applied in this area. Although the investigation was limited to the simulated rotation model of the magnetic induction gyroscope, all facets of the effort were equally applicable to the rotating model as well. The supporting electronic circuitry has been deliberately designed to accommodate either model of the gyroscope. The conclusions of the investigation indicated possible troubles in electrical grounding and shielding. As a consequence, the entire polarizing coil circuitry was revised to include as much shielding as possible. All d-c circuitry and a d-c control panel were included in this operation. With reference to grounds, test equipment in use was isolated from power line ground. Both high and low signal inputs and outputs were shielded; the shields in turn were electrically connected to a good ground (the metal of the screen room in which the equipment is being operated). It must be emphasized that the difficulties experienced with second harmonic distortion are highly unusual, since the 52 kc signal levels in the polarizing coil are, approximately, only one-millionth of the fundamental 26 kc signal levels. Quantities ordinarily considered "negligible" in most applications become problems in the present research on the magnetic induction gyroscope.

Preliminary results of the preceding circuit revision indicated a considerable reduction in the second harmonic distortion effects (although not a complete elimination). However, further operation of the simulated rotation model with no apparent circuit changes resulted in the effects of this second harmonic distortion again increasing and becoming a source of trouble. Thus the second harmonic problem still persists. An additional investigation is under way to trace sources of electric and/or magnetic fields. An instrument capable of making these measurements has recently become available and will be used in further tests.

The improvement of resonant signal magnitude was also under consideration during the current quarter. One of the most obvious apparent methods of increasing the magnitude of this signal is to increase the number of turns in the pickup coil surrounding the nuclear sample. This had proved to be difficult in the past because of excessive distributed capacity within the coil itself. This capacity tended effectively to reduce the Q of the pickup coil; thus

additional turns did not increase the signal magnitude since it is proportional to both the Q and the number of turns. Various types of wire were used in an attempt to optimize the pickup coil. The final conclusion, based also upon space as a factor, indicated that #34 A.W.G. litz wire would provide the least amount of distributed capacity with the highest Q. A pickup coil for use in the rotating model was wound using 1400 turns of this wire. A check of the electrical characteristics revealed that the Q of the new coil is about the same as that used in the simulated rotation model (approximately 40). The 400 additional turns, however, should result in a nuclear resonant signal of approximately 1.4 times the former value. More improvement is still available, since the present winding is split into two parts. The planned splitting into four parts should allow more turns (because of decreased distributed capacity), and as a consequence, a greater resonant signal.

## D. MAGNETIC INDUCTION GYROSCOPE ROTATING MODEL

Fabrication of the rotating model of the magnetic induction gyroscope was completed early in the current quarter. The winding of the polarizing and rotation-simulation coils occupied more time than planned primarily because of the type of wire that was used. A teflon insulated wire was employed but a measurement of the electrical parameters of the coils (inductance and resistance) revealed unacceptable values, since two like coils did not have identical characteristics. Because of this, formvar insulated wire was substituted; this wire produced no undesirable results. Attempts were made to hold coil spacing and dimension tolerances to 0.001 inch, but various factors prevented achievement of better than 0.005 inch tolerance. The use of a digital computer was required for a complete analysis of magnetic field conditions based upon the above tolerances. For this analysis, many different configurations of coil spacing and dimensions within the 0.005 inch tolerance were used in the actual computations. The analysis indicated that the required homogeneity could be obtained over the planned 3.25 centimeter nuclear fluid container under the worst configuration. Photographs of the rotating model exclusive of the rotating capacitor, air drive, and slip ring assemblies appear as Figures 1 and 2.

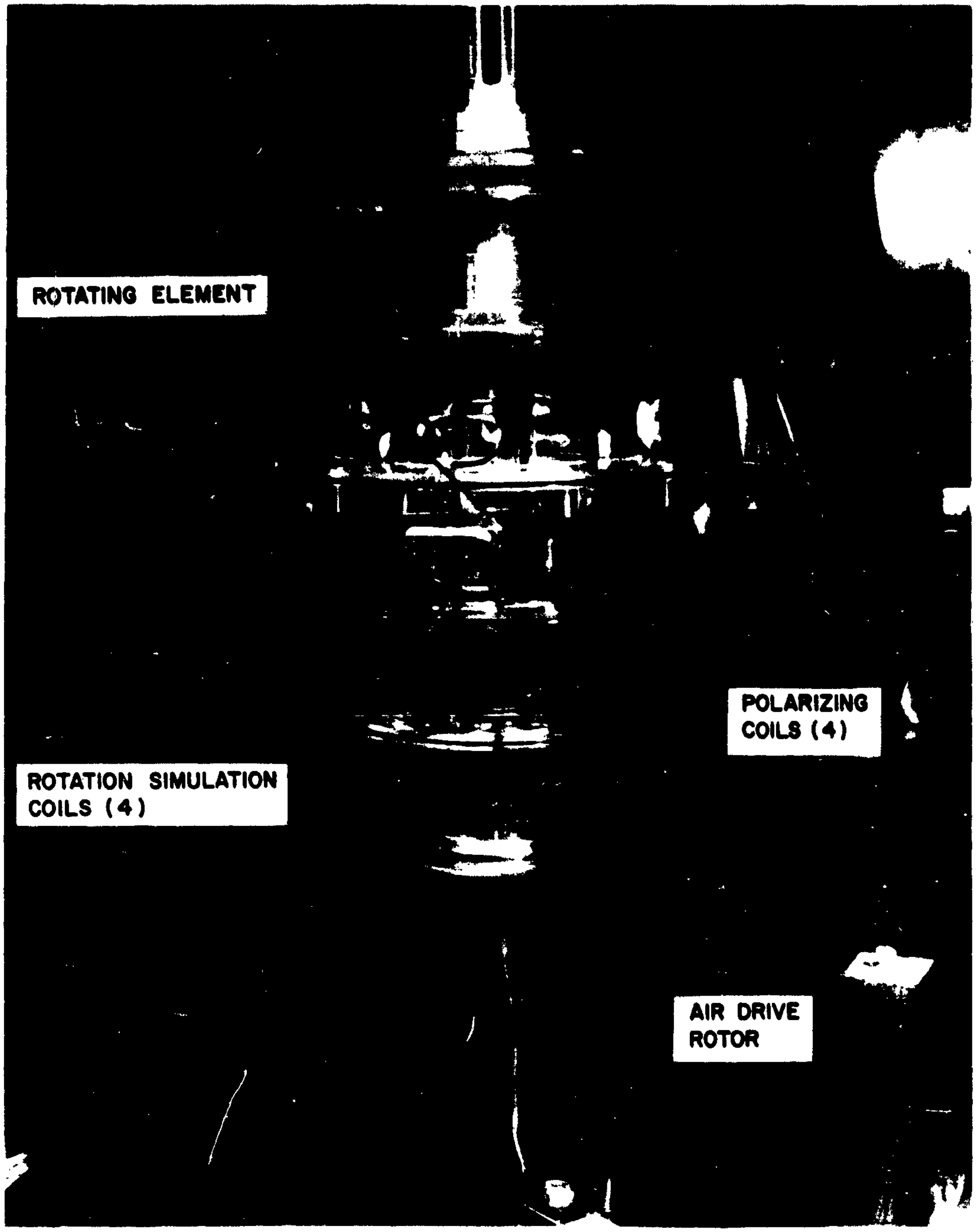


Figure 1 - Magnetic Induction Gyroscope Rotating Model

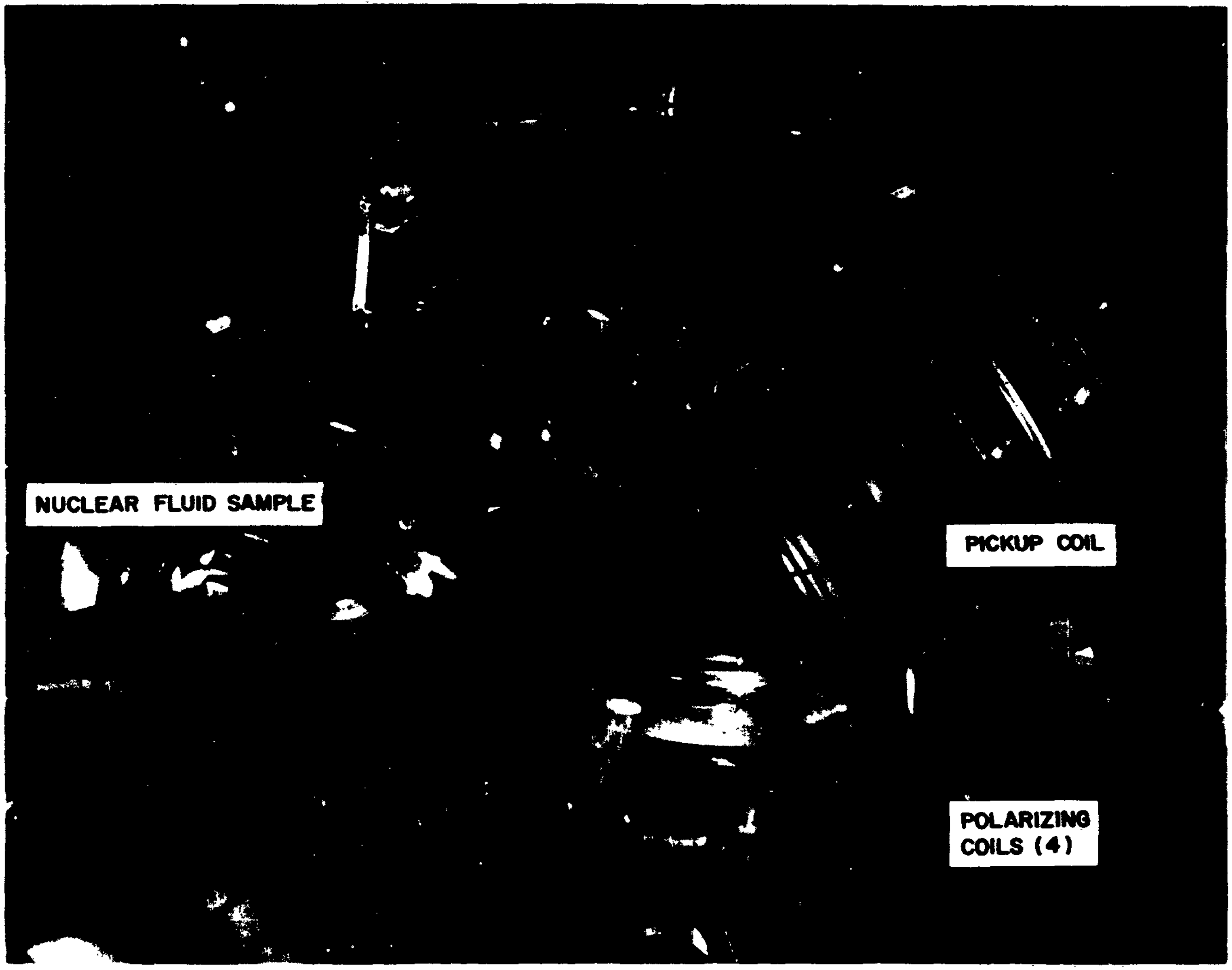


Figure 2 - Details of Magnetic Induction Gyroscope Rotating Element

Preliminary experimentation with the rotating model began with initial test conditions duplicating those of the simulated rotation model. The decision to begin with these tests was based upon the fact that the simulated rotation rate of 8.5 rps will introduce new engineering problems involving stability of magnetic fields. This is due to the planned use of pure water as a nuclear sample with a relaxation time in the order of one second. The long relaxation time will require the polarizing current to have, at the very least, a stability of 0.01% for one second. It was felt that the establishment of nuclear resonance under less exacting conditions should provide a good starting point for the more complex conditions associated with actual rotation.

Although these preliminary test conditions were relatively basic, a completely successful simulated rotation test has not been made to date because of problems in the mechanical positioning of the pickup coil-fluid housing assembly. A nuclear resonant signal was thought to be observed, but the presence of a high residual noise signal at 52 kc prevented complete verification. The test was also incapable of being repeated because of the mechanical adjustment problems.

As a consequence, it was felt that an analysis of the mechanical assembly of the rotating model was necessary. The result of the analysis was to indicate that the fundamental problem lies in the rotating assembly itself, i.e., the necessity for actual rotation coupled with the precise tolerances required for adequate magnetic field homogeneity. The original design of the rotating model could not foresee these difficulties because of their highly unusual nature. It was thus decided that some changes in construction were necessary to provide greater accessibility to the adjustment and also to improve the degree of adjustment. One of the primary difficulties has been caused by the gimbal pivots separating the various subassemblies. These pivots were necessary for providing adjustments about two axes. Because of the precise positioning required, even slight lateral pivotal motions caused large electrical positioning errors.

The foregoing problems have been taken into account in the redesign of the rotating model inner assembly. In addition, an adjustment allowing continuous rotation of the pickup coil-fluid housing assembly is being provided.

This type of adjustment has been found to be quite critical in the simulated rotation model. Final arrangements are being made to fabricate the new assembly. Concurrently, temporary minor modifications are being made to allow further work on the rotating model.

## SECTION III - PROJECTED ACTIVITIES

Work activities during the next quarter will be directed to the establishment of nuclear resonance first through duplication of simulated rotation tests, and then with the more precise conditions required for actual rotation. This second test will also use simulated rotation, but conditions will duplicate those of rotation with the exception of the rotation-simulation coils providing the equivalent rotation field. Prior to these activities, the design changes discussed previously will be incorporated into the rotating model.

The problems dealing with second harmonic distortion will continue to be investigated. The simulated rotation model will be used for this investigation, since the mechanical problems associated with the rotating model would be a source of interference. It is hoped that the availability of the new field tracing instrument discussed earlier will provide an insight into this problem.

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